RESTORATION OF DYNAMIC ECOSYSTEMS: LESSONS FROM FORESTED WETLANDS

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Summary

Bottomland hardwood forests once covered a vast area of the southern United States. Flood control and drainage projects encouraged clearing these forests for agriculture. Today, however, there is a reverse trend toward restoration of these vital ecosystems. Nevertheless, hydrologic modifications will continue to influence species composition and biological diversity, primary productivity, and the ultimate success of restoration efforts. Additionally, natural successional processes will influence restoration success. Natural succession in these ecosystems results from both autogenic and allogenic processes and the patterns of succession vary by landform within the floodplain. Sites undergo continuous change from sediment deposition and stream meandering. Restoration guidelines generally recommend identifying older, relatively undisturbed stands to use as the criteria for successful restoration. These reference sites, while chosen to represent the desired future condition of the restoration site, may have experienced altered hydrology. The interaction of succession and hydrology under natural conditions is dynamic and complex. When one or both have been altered by human intervention, however, the present condition of a reference site may not be a feasible goal for the future condition of a restoration site.

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some examples of restoration projects. Our focus will be on illustrating the interactive influence of altered hydrology and vegetation dynamics (Niering 1990; Williard and Hiller 1990). First, however, we must be clear what is meant by restoration and the role of reference sites in guiding restoration efforts.

Restoration Defined

Restoration of a forest ecosystem is necessary when forest vegetation has been removed and natural regeneration processes have been truncated by such severe disturbance or on-going manipulation of the site that restoration of forest vegetation is unlikely within an acceptable timeframe. For example, conversion of forestland to modern agriculture involves first removing the forest vegetation and, through mechanical or chemical means, suppressing regeneration of woody species from root sprouts, buried seed, or propagules brought to the site by wind, floodwater, or animals and birds. Once manipulation of the site ceases, forest vegetation will return, although often not quickly enough to suit our preferences (Clewell and Lea 1990). Thus, restoration projects typically occur where soils and, to a lesser extent, hydrology are intact (Clewell and Lea 1990). Restoration should not be confused with rehabilitation. Rehabilitation is needed to improve species composition, stocking, or growth in young or degraded forest stands (Clewell and Lea 1990; Maini 1992).

The goal of restoration is broader than simply establishing a tree canopy of a few selected species. Functional replacement of the natural system is the ideal, nevertheless in practice we recognize the impossibility of achieving this goal (Kusler and Kentula 1990). Cairns (1986), however, suggested that most functional attributes are correlated to vegetation structure and composition. Establishment of multispecies stands that quickly attain complex vertical structure is the focus of some current research (Stanturf and Shepard in press).

Restoration guidelines generally recommend identifying older, relatively undisturbed stands to use as the criteria for successful restoration. Sharitz (1992), for example, stressed the need to compare functions of natural and restored forests. Clewell and Lea (1990) pointed out the drawbacks of using specific reference forests to gauge success: (1) fully developed forests (i.e., vegetation canopy) provide more functions than young stands that have not reached canopy closure; (2) there is often little similarity in stands of the same community type, as measured by similarity indices, due to accidents of dispersal or localized disturbances. To this we would add that past stand manipulations, either by silvicultural treatments or by high-grading, will have changed species composition and stand structure.

Although there are drawbacks to using reference sites to measure success in restoration projects, they are useful in defining goals. A restoration site, once developed, should fit within the range of species composition and stand structure for that forest type, as it occurs in the vicinity (Clewell and Lea 1990). Reference sites can be chosen which represent the desired future condition of the restoration site. Care must be taken, however, to establish a hydrological record for both the restoration and reference sites. Extensive levee and drainage construction, for example, have isolated large areas of the LMAV from infrequent but regular flooding of the mainstem Mississippi and its tributaries. Sites in the LMAV outside the levees are "drier" now than historically, and older stands in some areas were therefore established under "wetter" conditions. One consequence is that the current preference for establishing oak plantations (Haynes et al. in press) on wildlife management areas could result in greater occurrence of oak regionally than was typical of the pre-colonial forest (The Nature Conservancy 1992).

Within the mainstem levees, called the batture lands, hydrologic modifications such as straightening channels by dredging have severely constrained normal river behavior. One consequence is that point bars, the "new" land critical for natural cottonwood (*Populus deltoides*) regeneration, are no longer formed. This will seriously reduce the future supply of cottonwood sawtimber (Parks, pers. comm., 1993).

Vegetation Dynamics

Restoration of forested wetlands requires first of all an understanding of site variation within floodplains and site requirements of the species to be used. Even though most forested wetland areas are relatively flat, large differences in site quality exist, and many restoration efforts have been unsuccessful because of failure to recognize these differences. Elevational differences of only a few inches can have a marked effect on site and therefore on species occurrence and development (Hodges and Switzer 1979). Differences in hydrology, i.e., drainage and soil moisture, is the site factor most obviously associated with these minor elevational differences, but they also reflect differences in soil type, texture, structure, and pH, all of which affect species suitability for the site.

The discussion which follows of geomorphic sites, species-site relationships, and ecological succession will apply primarily to major stream valleys of the Mississippi Alluvial Valley and the Gulf Coastal Plain. Slight differences, especially in species occurrence and associations, occur in floodplains of the Atlantic Coastal Plain and in minor bottoms of the Gulf Coastal Plain, but the principles, as they relate to restoration, are the same.

Figure 2 (Mitsch and Gosselink 1993) illustrates the relationship between major geomorphic features of a southeastern U.S. floodplain and Figure 3-a (Hodges and Switzer 1979) is a hypothetical depiction of a cross section of a major stream valley of the Gulf Coastal Plain. Each topographic feature shown in Figure 3-a may occur several times and not necessarily in the order shown. Bars or point bars are formed when the concave section of stream banks erode and the sediment is deposited downstream on an opposite convex area of the stream channel. With time and increased deposition, the bar may become a mud flat and may eventually be raised to the level of the current front or natural levee. If the stream continues to move across the floodplain, as illustrated in Figure 2, ridge and swale topography typical of many coastal plain stream valleys will be formed.

The origin and development of these floodplain geomorphic features are discussed by Hodges (1994a) and detailed descriptions, including relative elevation, soil types, drainage class, and productivity are given by Hodges and Switzer (1979). In summary, the fronts and ridges (former fronts) are the highest, best drained, and most productive sites within the floodplain. Soils are generally sandy or silty loams. Soils on the flats are predominantly clays and the sites are poorly to somewhat poorly drained. Sloughs and swamps arise from old streambeds which are almost filled or being filled with sediment. The soils are usually fine textured and drainage is poor. Standing water may be present in the swamps except in extremely dry years.

The relationship between geomorphic site positions and species occurrence is discussed in detail by Hodges and Switzer (1979) and Hodges (1994b). Some typical species associations for major streambottoms of the Gulf Coastal Plain and Mississippi Alluvial Valley are depicted in Figure 3-b, but as will be discussed, variations occur depending on stage of succession. For example, the elm-ash-sugarberry (*Ulmus americana, Fraxinus pennsylvanica, Celtis laevigata*) association is common on ridge and flat sites, but does not usually occur on new land and in the very wet sloughs and swamps. Black willow (*Salix nigra*) and cottonwood (*Populus deltoides*) are the most common species on the new land near the river. Greatest species richness and diversity most often occur on the front and ridge sites and may include sweetgum (*Liquidambar styraciflua*), a number of bottomland red oaks, swamp chestnut oak (*Quercus michauxii*), and hickories (*Carya spp.*) in some stream bottoms. Composition on the flats can be extremely variable depending primarily on drainage. Overcup oak (*Quercus lyrata*), water hickory (*Carya aquatica*) and baldcypress (*Taxodium distichum*) may predominate on the wettest areas and elm-ash-sugarberry on the somewhat better drained areas, but often with a good mixture of Nuttall (*Quercus nuttalli*) and willow oak (*Quercus phellos*). Overcup oak, water hickory, green ash, and persimmon (*Diospyros virginiana*) are common associates in sloughs. The baldcypress-water tupelo (*Nyssa aquatica*) type is most common in the swamps but, depending on depth of flooding, swamp tupelo (*Nyssa silvatica var. biflora*), water elm (*Planera aquatica*), Carolina ash (*Fraxinus caroliniana*), water hickory, swamp laurel oak (*Quercus hemisphaerica*), and overcup oak may occur.

A knowledge of natural successional patterns on bottomland sites is also important for long-term success of restoration projects. Succession and the forces driving it are very different in bottomlands than on most upland sites. On upland sites, succession is driven primarily by autogenic forces -- one community of plants creates an environment more suitable for establishment of other species than for themselves. Plant succession on bottomland sites is the result of both autogenic and allogenic processes. In addition to plant-mediated changes, the site can change over time due to deposition. Small differences in elevation can result in great differences in site quality primarily because of differences in hydrology. Species occurrence and natural patterns of ecological succession within the floodplain are strongly influenced by these differences in elevation and rates of deposition.

Hodges (1994a,b) presents information on successional patterns on floodplain sites. Three general patterns of succession are recognized in major bottoms. One pattern occurs on permanently flooded sites where very little deposition occurs, such as baldcypress-tupelo swamps. Succession is "arrested" on these sites, and compositional changes may not occur for hundreds of years without disturbance. The baldcypress-tupelo type represents the oldest type (oldest trees) on the floodplain. Stands can be 200-300 years old before breakup occurs.

Two other patterns of succession are illustrated in Figure 4. One pattern, Figure 4-a, occurs on poorly drained sites at low elevations. The pioneer tree species on these sites with heavy soils is usually black willow, but it is a short-lived species. Breakup of most stands may begin as early as age 30 and few remnants survive beyond age 60 (Johnson and Shropshire 1983). As illustrated in Figure 4-a, successional pattern depends on the rate of sediment deposition and sometimes on the texture of the sediment. It is significant that all patterns of succession shown in Figure 4-a tend toward the elm-ash sugarberry type, which is the most common forest type in the major bottoms of the Mississippi River alluvial plain and the Gulf Coastal plain. Progression to the regional oak-hickory climax is not well documented, but evidence for it exists such as at Big Oak State Park in Missouri. Where the sites build rapidly, the time from pioneer species to climax has been estimated to be about 600 years (Shelford 1954).

Another pattern of succession, Figure 4-b, occurs on the higher elevation, better drained ridge and front sites. Cottonwood is the pioneer species on "new" land or after allogenic events resulting in removal of previous communities and exposure of mineral soil. However, breakup of cottonwood stands may begin as early as age 45 and very few remnants survive to age 80-100 (Johnson and Shropshire 1983). Stand composition following the cottonwood association can be extremely variable and depends primarily on how the cottonwood stand breaks up. Tolerant species such as boxelder (*Acer negundo*), sugarberry, silver maple (*Acer saccharinum*), and hackberry (*Celtis occidentalis*), usually well established beneath cottonwood stands, will capture the site if the stand breaks up gradually. If break up is more rapid, the cottonwood may be replaced by a number of species depending on the advance regeneration and the ability of intolerants to become established. In the Mississippi River system composition may be primarily sycamore (*Platanus occidentalis*), pecan (*Carya illinoensis*), and elm (riverfront association), but species such as ash, sweetgum, willow oak, and water oak are usually present. The riverfront association may endure for 75-125 years. As on the wetter sites, the tendency is toward an elm-ash-sugarberry type which may replace itself and endure for 200-300 years. A transitory sweetgum-oak type can occur following opening of the site by natural disasters or heavy cutting, but this depends on the presence of advance regeneration and/or coppice regeneration. The sweetgum-oak type may persist for 200 years or longer. When flooding and sedimentation essentially cease and soils start to mature, the regional oak-hickory climax will begin to appear. According to Shelford (1954) this association may begin with oaks such as cherrybark (*Quercus pagoda*), pin (*Quercus palustris*), and swamp chestnut and take 200 years or more to progress to an oak-hickory climax. At that stage, with infrequent and short duration flooding, the site may function more like a terrace than a ridge site on a floodplain.

Current Restoration Practice

Techniques for planting and direct-seeding bottomland hardwoods are available. Direct-seeding, although less expensive than planting seedlings, is limited to oaks and other heavy-seeded species (Kennedy 1994). Direct-seeding and planting seedlings can be accomplished by hand, using very simple and inexpensive tools. Methods for mechanical planting and sowing are faster, but generally require more expensive preparation of the planting site. Efforts are underway to develop aerial seeding methods.

The literature on bottomland hardwood restoration is substantial (Haynes et al. 1988), but much needs to done (Clewell and Lea 1990; Sharitz 1992). Major research emphasis today is on characterizing reference sites to guide restoration efforts; new reforestation techniques, such as intercropping; methods to establish mixed species stands; and on the effects of restoration at the landscape level.

Intercropping cottonwood with Nuttall oak is a technique designed by James River Timber Corporation, who is already using it in its private landowner reforestation assistance program. The rationale for this novel technique is to use cottonwood as a nurse crop that improves the conditions for oak survival and growth. This treatment was explicitly designed to provide early income from timber as an economic incentive to encourage private landowners to reforest these degraded wetlands. The nurse crop concept is well-known in silviculture (Matthews 1989) and has been recommended for reforestation of abandoned agricultural fields (McKevlin 1992). However, no data are available to compare it to other more commonly used reforestation methods.

A major research challenge today is restoring mixed stands that quickly acquire the kind of structure found in natural stands. Restoration efforts in the past have concentrated on establishing single-species plantations. The appearance of a plantation can be avoided by altering the pattern of planting, for example by planting in wavy lines rather than straight rows. Other modifications will be necessary to establish stands with a canopy structure that maximizes avian diversity (Stanturf in press). Multispecies plantations can be established in several types of mixtures (Goelz in press). Intercropping mixtures (single species rows) and mixed monotypes (species in block plantings) produce an overall mixture, but species are clumped in a way that does not mimic natural conditions. Methods for establishing true mixtures will require basic information on how species compete with each other during early stand development, especially after crown closure. Because early growth of some species can be quite slow, they can be overtopped by competitors. In addition to inherent growth rates, competitive ability is affected by environmental conditions such as soil properties and flooding frequency and duration (McKnight et al. 1981).

Most reforestation work occurs in small patches, except for a few large public projects. Many researchers have discussed the effects of fragmentation on wildlife, particularly area-sensitive, interior-dwelling neotropical migratory birds (Robbins et al. 1989; Wilcove and Robinson 1990). Gosselink et al. (1990) reported a case study of the 1 million hectare Tensas Basin in Louisiana and used island biogeographic theory to plan a reforestation effort. Few, however, have documented the benefits of reforesting in large blocks, particularly when existing large patches are to be connected by corridors. The Lake George Restoration site in Mississippi provides an opportunity to evaluate this hypothesis. The restoration site connects two of the largest blocks of natural and restored bottomland hardwood forests in the LMAV, the Delta National Forest and Panther Swamp National Wildlife Refuge (Figure 5). Wildlife use of the area prior to, and following, restoration is being evaluated (Corp of Engineers 1989).

Another example of ongoing wetland restoration efforts is associated with several thermally-impacted, low order streams at the Savannah River Laboratory near Aiken, SC. Discharges of water with elevated temperatures into Pen Branch and Four Mile Creek have eradicated the woody vegetation that was typical for forested floodplains of the SE U.S. As a result, herbaceous species such as cattail (*Typha* spp.) and blackberry (*Rubus* spp.) and light-seeded woody species such as black willow now occupy sites once dominated by mixtures of *Nyssa, Quercus*, and *Acer* spp. (among others).

In addition to their high temperatures, discharges from the K reactor were as much as 10 times greater than normal highwater on Pen Branch and Four Mile Creek, resulting in substantial channel erosion and deposition of a broad delta downstream. Approximately half of the 200 hectare delta formed on Pen Branch is regenerating naturally from the adjacent backwater swamp forest of the Savannah River (McKee 1994). The remaining portion of the delta and the floodplain upstream is the focus of restoration efforts.

Because of the higher elevation of the sediments, and reduced backwater flooding into Pen Branch caused by dams on the Savannah River (Sharitz and Lee 1985), the choice of species for restoration could not be guided strictly by the pre-impact conditions or the unimpacted forests nearby (McKee 1994).

Therefore, transects were established across the restoration site to monitor hydroperiod during the growing season and species were selected based on their tolerance to flooding.

Reforestation is directed toward planting baldcypress and water tupelo in wetter areas with water hickory, green ash, swamp chestnut oak, willow oak, cherrybark oak, persimmon and beech being considered for better-drained portions of the floodplains (McKee 1994; Dulohery et al. in press). These enrichment plantings are coupled with intensive efforts to control competing vegetation. Aerial and backpack applications of herbicides will be used to control both herbaceous and undesirable woody species. In a limited number of locations, manual suppression may be used to reduce standing woody material.

It is anticipated that the combination of enrichment plantings and competition control measures will restore vegetation communities that approach the structure and species assemblages which are characteristic of floodplain forests. In turn, the re-establishment of such communities should promote the multiplicity of functions typically associated with riparian forests. Future plans call for assessment of the degree to which habitat, biogeochemical, and hydrologic functions are restored. It is interesting to note, however, that the heavily impacted site was regenerating naturally once the thermal discharges ceased. Succession had been setback to the initial stage of "new" land, i.e. bare mineral soil, and invasion by black willow is quite advanced. Restoration was undertaken because the estimated 50 years needed for natural stand development was judged too long (McKee 1994).

Lessons From Dynamic Systems

Hydroperiod is the driving factor in these dynamic systems, and relatively minor differences in topography can substantially affect vegetation composition. It is absolutely critical to establish the current hydrology of a restoration site to determine which species are suitable for planting. Our rule of thumb in the LMAV is to acquire at least a 5-year record of growing season flooding (Stanturf in press).

An understanding of hydrology is also critical in locating a suitable reference site. In areas where extensive clearing has removed most of the former vegetation, suitable reference sites may simply be unavailable. One is left, in that case, to infer suitability of species from information on species preferences for site characteristics. On the other hand, nearby forests may not be suitable references sites if the hydrology of the restoration site has been altered. Such was the case in the portions of Pen Branch where sedimentation had raised the elevation of the site. Other examples abound where upstream hydrologic alterations such as dams have changed hydrology.

Another pitfall to avoid is extrapolating from mature vegetation on a reference site which has altered hydrology. In areas of drainage and levee construction, such as in the LMAV, regional hydrology has changed substantially within the lifetime of mature stands. The conditions under which stands were established may no longer be operating. Cypress, for example, can tolerate continuous flooding under certain conditions yet requires unflooded conditions to regenerate naturally. Highway construction, levees, impoundments, and drainage systems can alter hydroperiods such that swamp areas no longer experience dry years, making it impossible for cypress to regenerate from seed.

Whether or not a suitable reference site can be located, it is imperative that species preferences and tolerances are matched to the characteristics of the site, in particular inundation regime. Relative flood tolerance of bottomland hardwoods were summarized by McKnight et al. (1981). Inundation regime is more complex, however, than whether or not a site floods. Depth, time, and duration of flooding must be considered, as well as the state of the floodwater, particularly flowing versus stagnant (Hook and Scholtens 1978). Soil physical conditions, root aeration, nutrient availability, and moisture availability during the growing season are other important factors (Stone 1978; Baker and Broadfoot 1979).

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Figure Captions

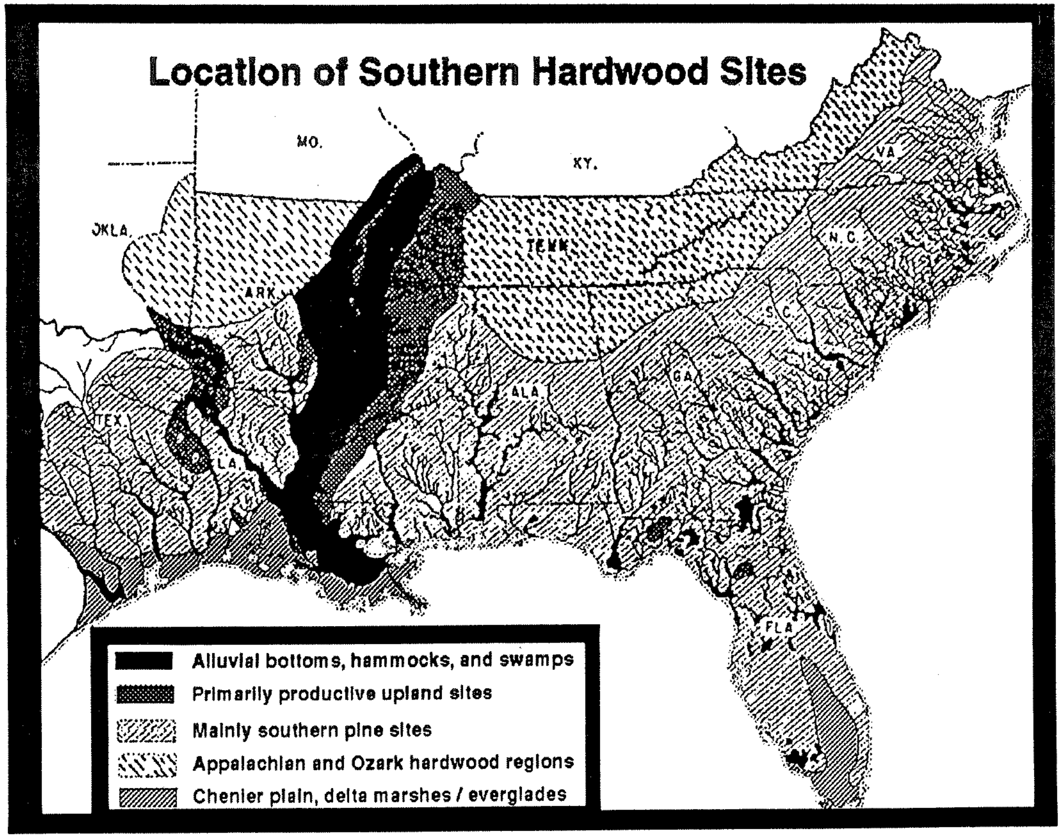
Figure. 1. Extent of bottomland hardwoods in the southern United States. (After Putnam et al. 1960).

Figure 2. Major geomorphic features of a southeastern United States floodplain. (After Mitsch and Gosselink 1993)

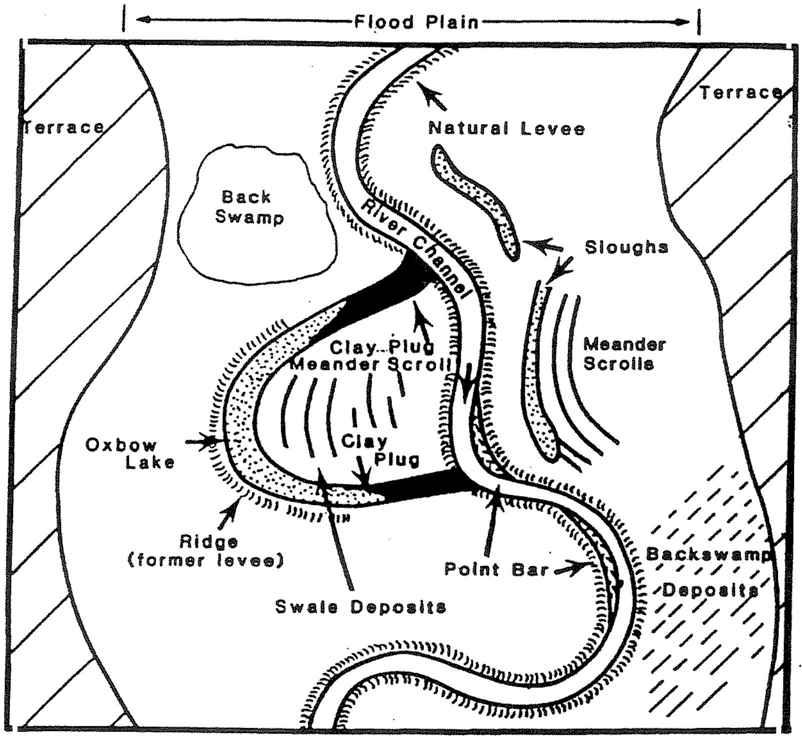
Figure 3. Generalized cross-section of a major stream bottom of the Coastal Plain. A. Major stream valley showing topographic positions. B. Species associated with topographic variations within a major stream valley.

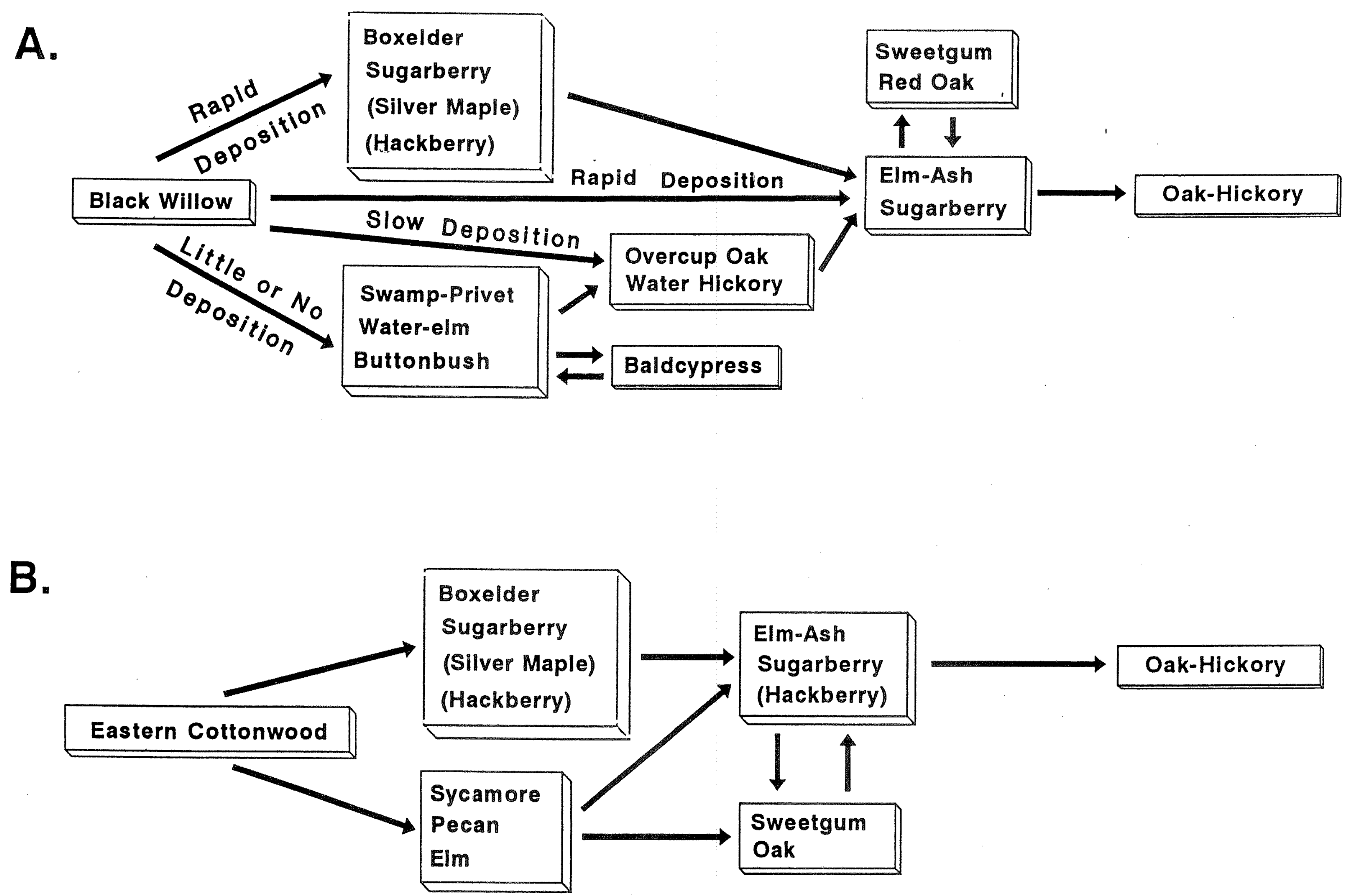
Figure 4. Patterns of natural succession in major stream bottoms. A. Succession beginning on poorly drained sites at low elevations in major bottoms. B. Succession beginning on better-drained higher-elevation sites in major bottoms.

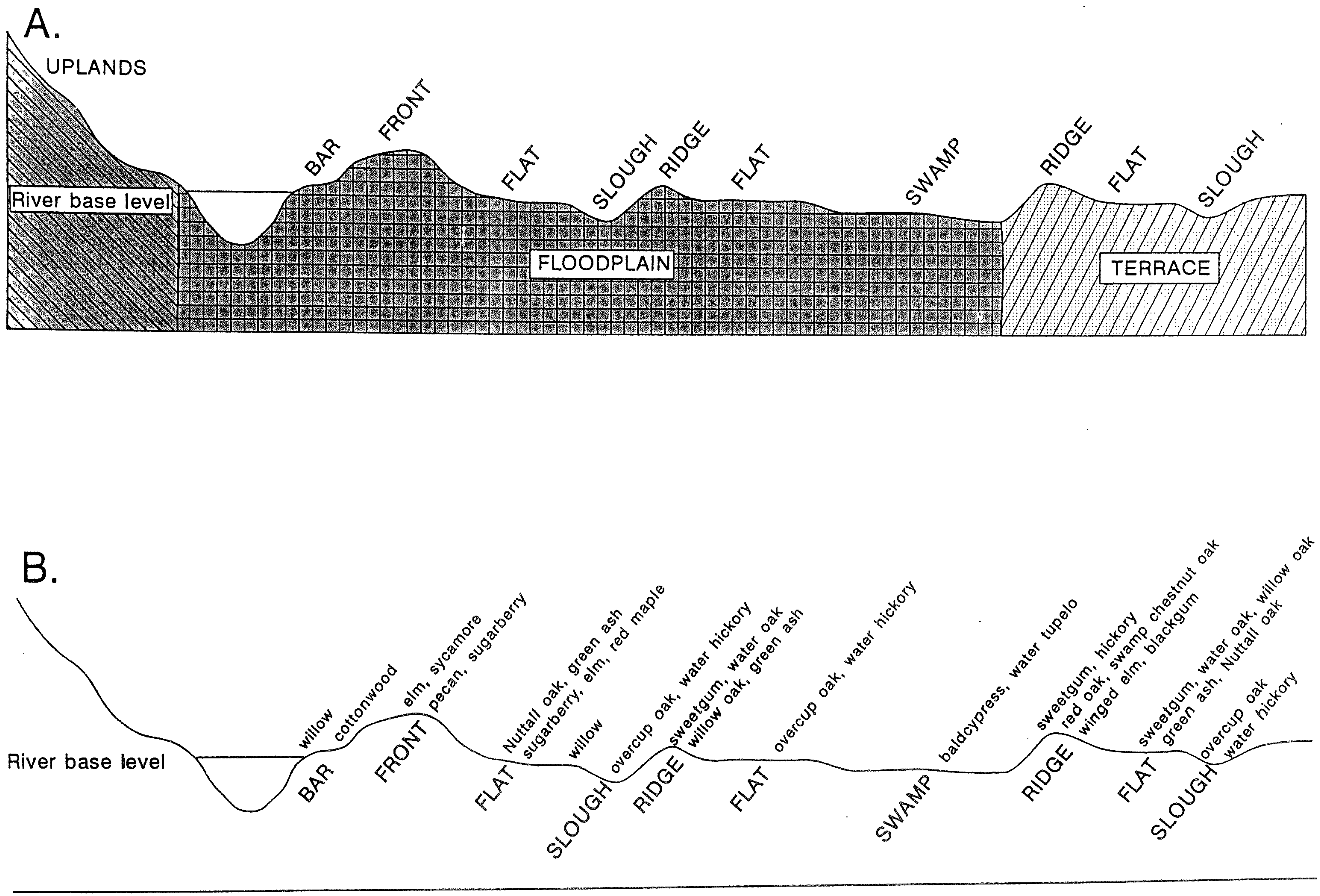
Figure 5. Lake George Wildlife Restoration Site in Mississippi.

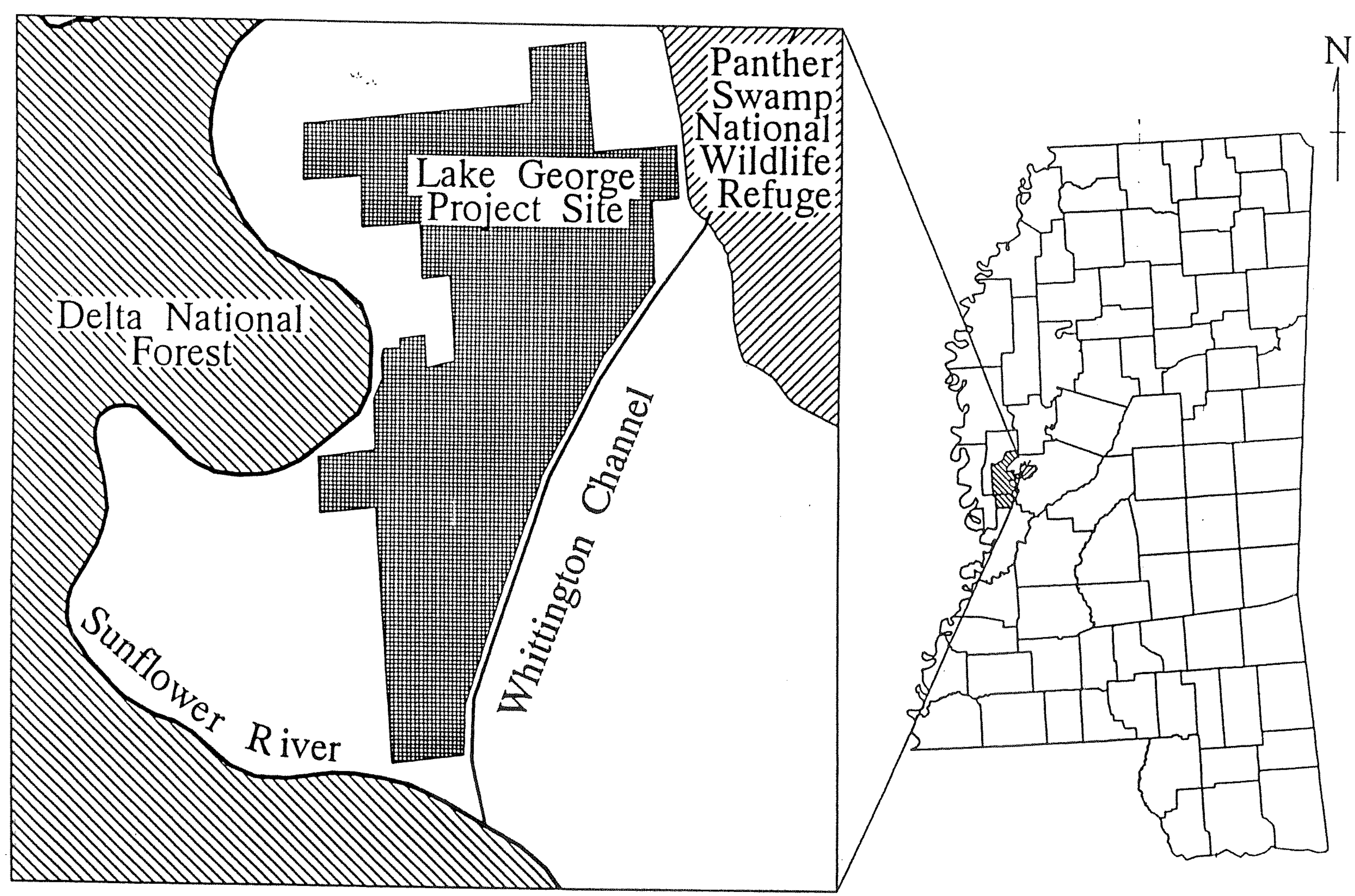


Location of Southern Hardwood Sites
MO.
KY.
OKLA.
TENN.
ARK.
VA.
N.C.
S.C.
GA.
ALA.
TEX.
LA.
FLA.
Alluvial bottoms, hammocks, and swamps
Primarily productive upland sites
Mainly southern pine sites
Appalachian and Ozark hardwood regions
Chenier plain, delta marshes / everglades


Flood Plain
Terrace
Terrace
Natural Levee
Back
Swamp
River Channel
Sloughs
Clay Plug
Meander Scroll
Meander
Scrolls
Oxbow
Lake
Clay
Plug
Ridge
(former levee)
Point Bar
Backswamp
Deposits
Swale Deposits


A.
Black Willow
Rapid Deposition
Boxelder
Sugarberry
(Silver Maple)
(Hackberry)
Rapid Deposition
Slow Deposition
Little or No Deposition
Swamp-Privet
Water-elm
Buttonbush
Overcup Oak
Water Hickory
Baldcypress
Sweetgum
Red Oak
Elm-Ash
Sugarberry
Oak-Hickory
B.
Eastern Cottonwood
Boxelder
Sugarberry
(Silver Maple)
(Hackberry)
Sycamore
Pecan
Elm
Elm-Ash
Sugarberry
(Hackberry)
Sweetgum
Oak
Oak-Hickory


A.
UPLANDS
River base level
BAR
FRONT
FLAT
SLOUGH
RIDGE
FLAT
SWAMP
RIDGE
FLAT
SLOUGH
FLOODPLAIN
TERRACE
B.
River base level
willow
cottonwood
elm, sycamore
pecan, sugarberry
Nuttall oak, green ash
sugarberry, elm, red maple
willow
overcup oak, water hickory
sweetgum, water oak
willow oak, green ash
overcup oak, water hickory
baldcypress, water tupelo
sweetgum, hickory
red oak, swamp chestnut oak
winged elm, blackgum
sweetgum, water oak, willow oak
green ash, Nuttall oak
overcup oak
water hickory
BAR
FRONT
FLAT
SLOUGH
RIDGE
FLAT
SWAMP
RIDGE
FLAT
SLOUGH


Panther Swamp National Wildlife Refuge
Lake George Project Site
Delta National Forest
Whittington Channel
Sunflower River
N